EVALUATING EXHAUST EMISSION PERFORMANCE OF URBAN BUSES USING TRANSIENT HEAVY-DUTY CHASSIS DYNAMOMETER

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VTT Processes, Engines and Vehicles

OUTLINE

- Background
  - HD engine emission legislation
- Advantages of complete vehicle testing (on chassis dynamometer)
- Features of VTT's heavy-duty emission laboratory
- Ongoing transit bus emission evaluation
  - Methodology
  - Results of 2002 and 2003 measurements
  - Conclusions

BACKGROUND

- HD engine emission certification is based on engine testing
  - Engines are run in engine dynamometers using specified load patterns
- In the US: HD Transient cycle used for several years
- In Europe: steady-state testing (ESC) is supplemented by transient testing (ETC, directive 1999/96/EC)
- Transient testing represents real-world conditions better than steady-state
- However, engine testing does not take the whole vehicle into account

BACKGROUND - EUROPEAN HD LEGISLATION

Certification testing according to Directive 1999/96/EC calls for:

From 2000 onwards:

- Diesel engines
  - ETC is required in addition to ESC (and ELR), if advanced emission aftertreatment is used for NO_X and/or PM control
- Natural gas engines
  - ETC only

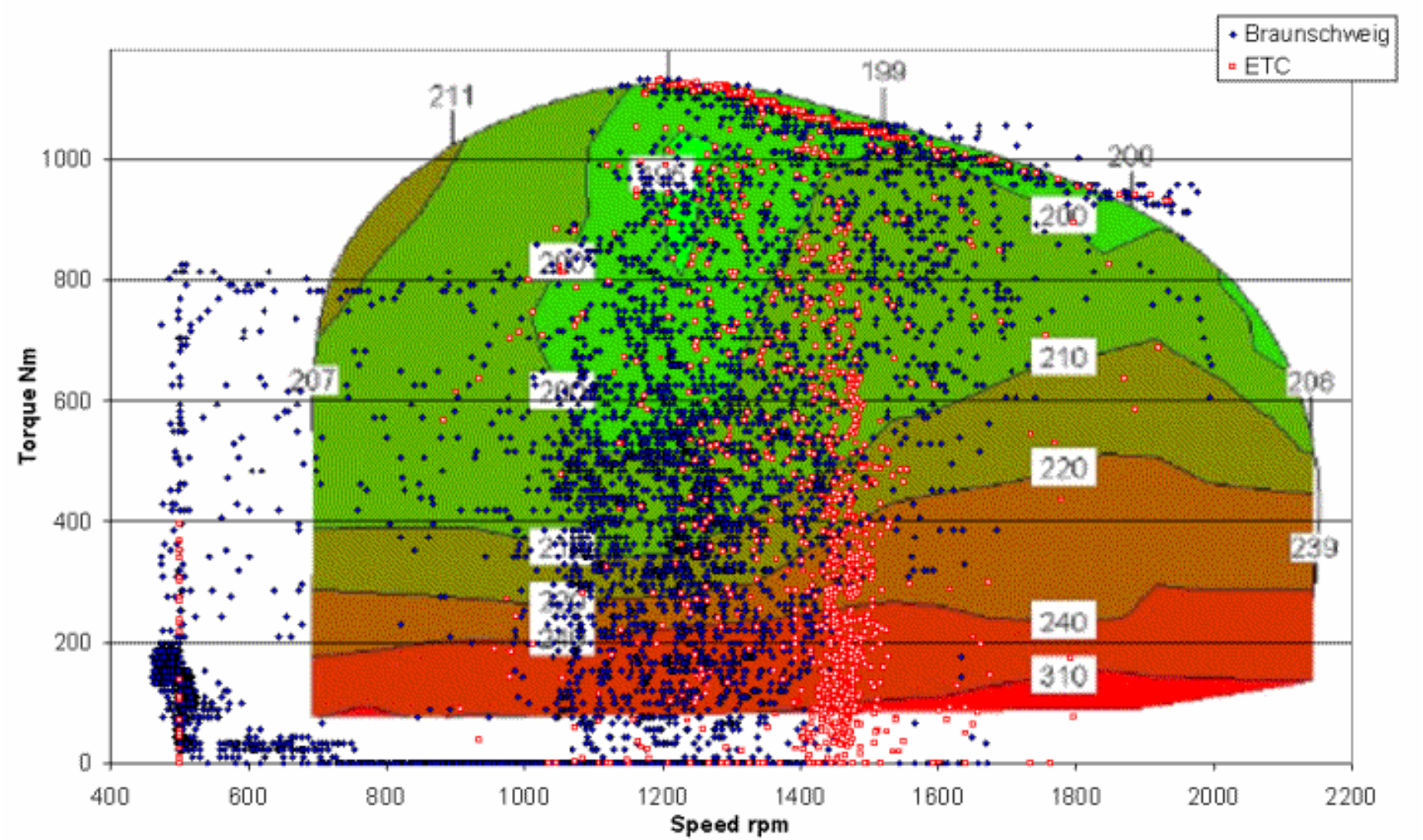
From 2005 onwards:

- Diesel engines:
  - ETC required for all engines
- Natural gas engines:
  - ETC only

WHY COMPLETE VEHICLE TESTING ?

- Engine testing does not account the properties of the vehicle
  - Vehicle weight and loading
  - Vehicle specific driving resistance at different speeds
  - Transmission properties etc.
- Evaluation of in-use vehicle emissions presents a problem
  - Dismounting engines from in-use vehicles for testing is costly
- Do the standardized engine test cycles represent real-life driving?
  - Complete vehicle testing easily enables comparison of different driving patterns
- The rationale for testing complete vehicles and VTT's new heavy-duty emissions laboratory were discussed in detail in Ikonen's presentation at DEER 2003

OPERATIONAL REGIMES CERTIFICATION VS. BUS CYCLE



HEAVY-DUTY EMISSION LABORATORY AT VTT MAIN COMPONENTS

- Road-simulation chassis dynamometer for complete vehicle testing
  - In-use vehicle emission performance
  - Evaluation of different real-life driving cycles
  - Emission deterioration evaluation along with vehicle aging
- Transient type engine dynamometer with fast response
  - ETC testing
  - High performance engine testing
- Full-flow CVS system
  - Secondary tunnel
  - Particle collector
- Exhaust emission analyzer set for regulated emissions
- Wide variety of instrumentation for unregulated emission measurements

HEAVY-DUTY EMISSION LABORATORY AT VTT CHASSIS DYNAMOMETER

- Road-simulation chassis dynamometer
  - Manufacturer Froude Consine Ltd, UK
  - Roller diameter 2.5 m
  - Inertia simulation 2 500 - 60 000 kg
  - Max axle weight 20 000 kg
  - Max tractive force ±20 000 N (speed range 0 - 54 km/h)
  - Max power absorption 300 kW (speed range 54 - 110 km/h)
  - Fast and precise IGBT control for good transient load response
  - Driver's Aid with programmable driving cycles

CITY BUS EMISSION EVALUATION

- National urban bus emission evaluation
  - Scheduled for 2002 - 2004
  - Emission factors will be generated for about 35 in-use vehicles
  - Vehicles represent different age groups, fuels and technologies
    - Euro 1 >> Euro 5 / EEV (Environmentally Enhanced Vehicle)
    - Both diesel and natural gas fuels are included
    - Diesel buses with and without exhaust aftertreatment
    - Natural gas buses with aftertreatment, both lean-burn and stoichiometric
  - Regulated emissions (CO, THC, NOX, PM) for all vehicles


CITY BUS EMISSION EVALUATION

- Additional IANGV's assignment with newest-technology CNG and diesel buses
- More comprehensive emission analyses:
  - Particulate size distribution
  - Chemical and biological characterization of particulates
  - Hydrocarbon speciation
  - Aldehydes
  - Semivolatiles
  - Anions (sulfates and nitrates)
- IANGV will publish a full report in October 2004

IANGV

CITY BUS EMISSION EVALUATION

- Bus selection criteria, for the general part:
  - Most common bus types
  - Several units of same bus type to evaluate consistency
  - A few buses repeatedly every year to evaluate ageing/deterioration

- Bus selection criteria, for the IANGV part:
  - Several newest technology NG buses, both lean-burn and stoichiometric
  - Relevant new diesel counterparts with and without aftertreatment for reference
  - Low mileage and flawless condition required


VEHICLES/IANGV BUS STUDY

Fuel	Brand	Model year	Euro class	Exhaust aftertreatment	Combustion
diesel	C	2003	3	-	diesel
diesel	C	2003	3	oxicat	diesel
diesel	C	2003	3	CRT filter	diesel
CNG	A	2002	3	oxicat	lean-burn
CNG	B	2002	EEV	oxicat	lean-burn
CNG	D	2003	EEV	TWC	lean-mix*)
CNG	E	2004	EEV	TWC	stoichiom.

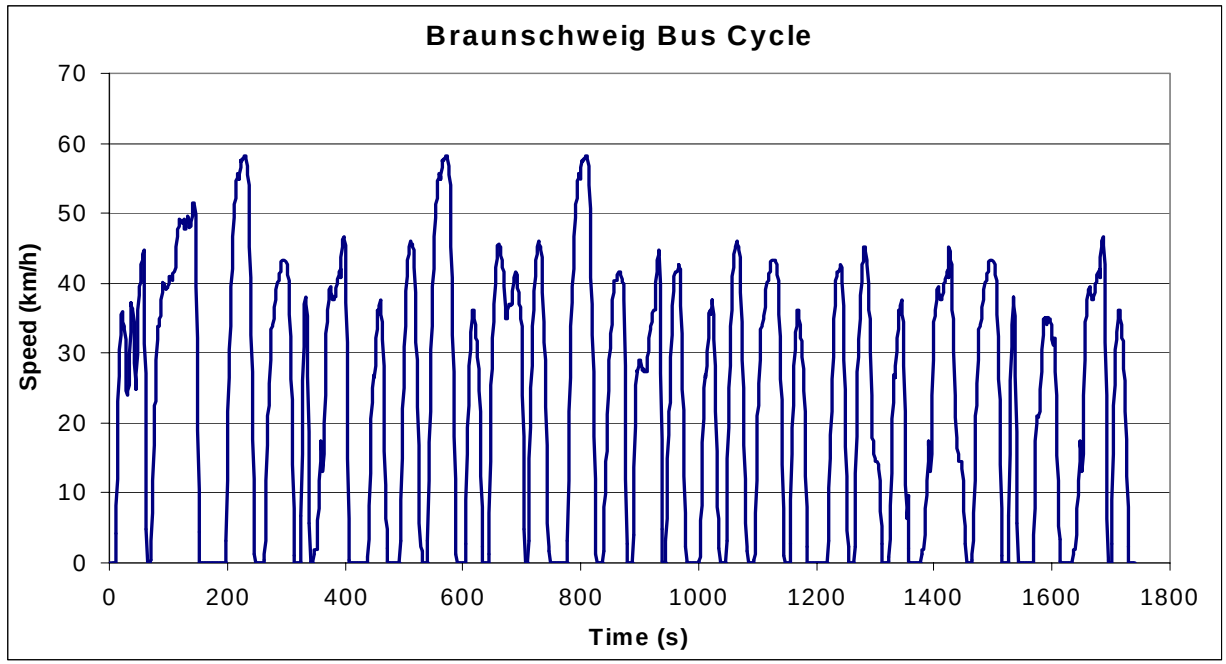
*) combination of stoichiometric and lean-burn combustion

CITY BUS EMISSION EVALUATION , METHODOLOGY

- Driving cycles
  - Braunschweig bus cycle (European)
  - Orange County bus cycle (US, SAE J2711)
- Vehicle loading
  - Tests with half-loaded vehicles, some checkpoints unloaded
- Test fuels
  - Ultra low sulphur commercial diesel
  - Natural gas of high methane content (98 %), sulphur free (no odorant)

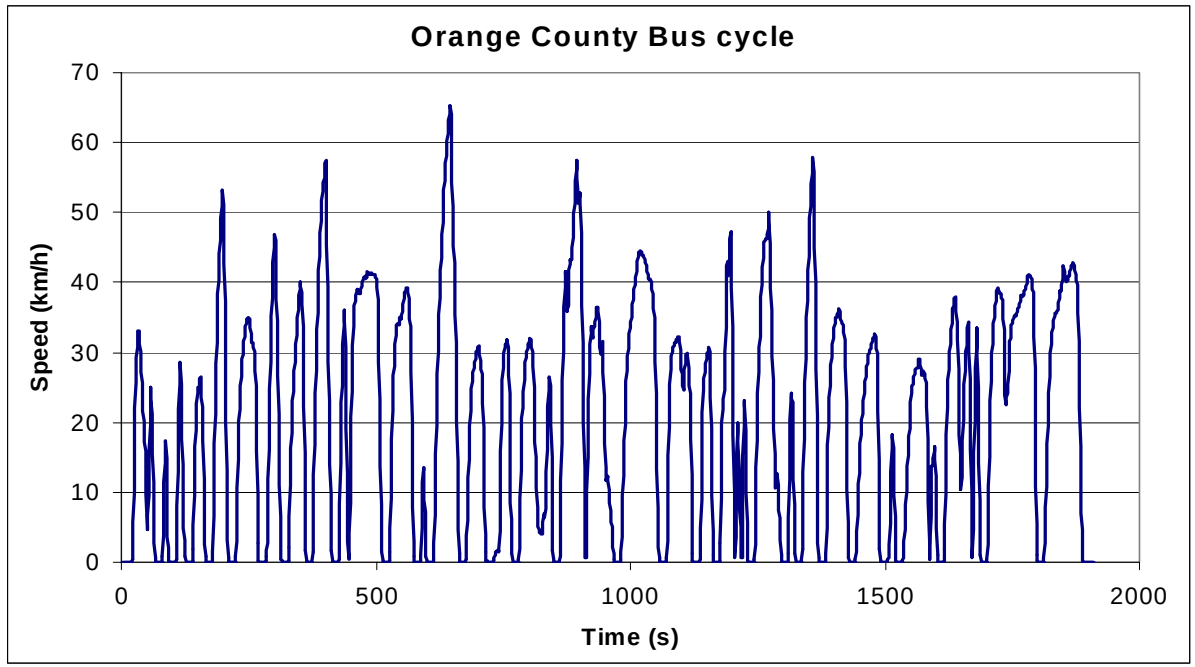
CITY BUS EMISSION EVALUATION, METHODOLOGY

- Braunschweig urban bus cycle
  - duration 1740 s
  - length 10.873 km
  - average speed 22.5 km/h
  - max speed 58.2 km/h
    share of idle 25%

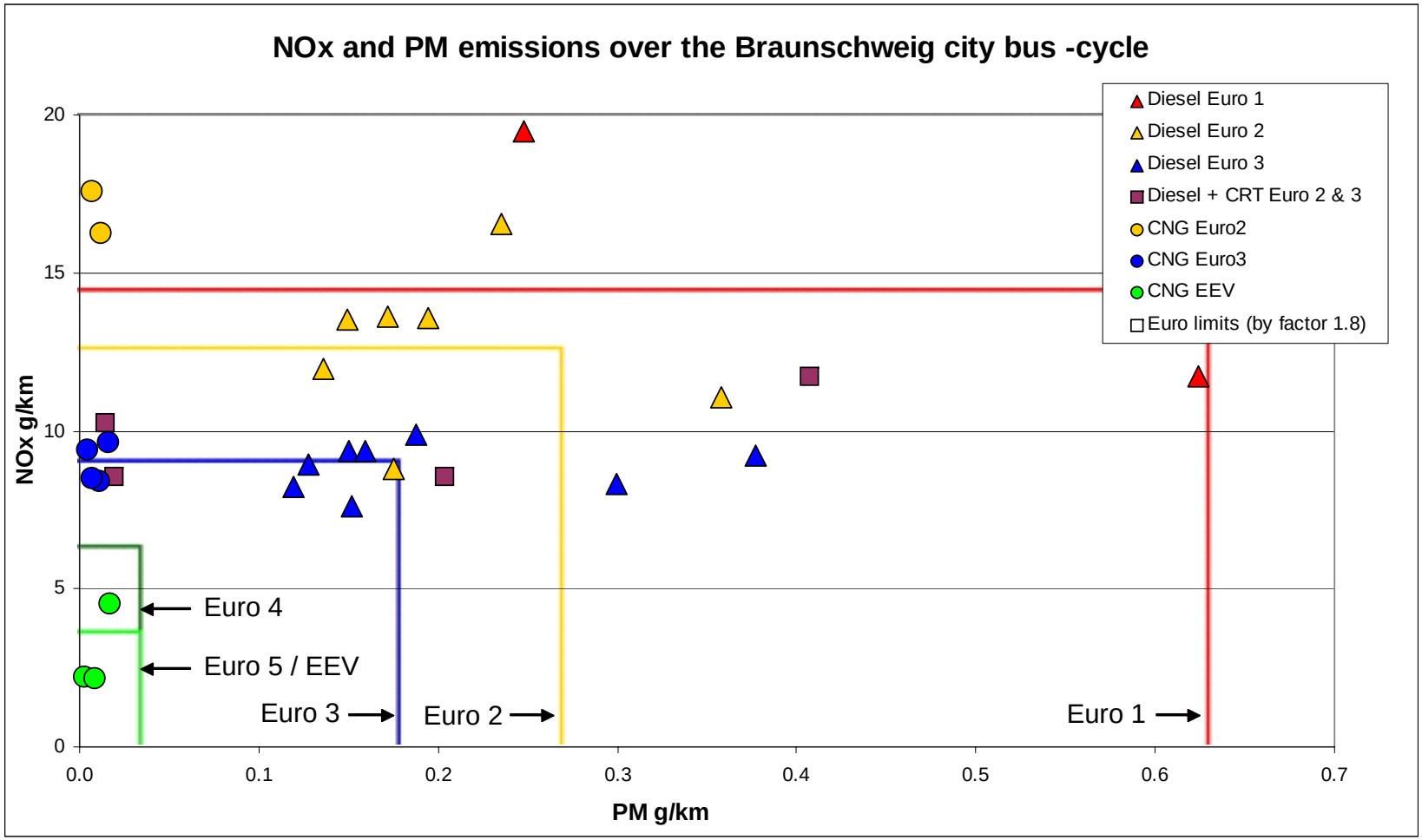


CITY BUS EMISSION EVALUATION, METHODOLOGY

- Orange County bus cycle
  - duration 1909 s
  - length 10.526 km
  - average speed 19.9 km/h
  - max speed 65.4 km/h
  - share of idle 21%



CITY BUS EMISSION EVALUATION RESULTS



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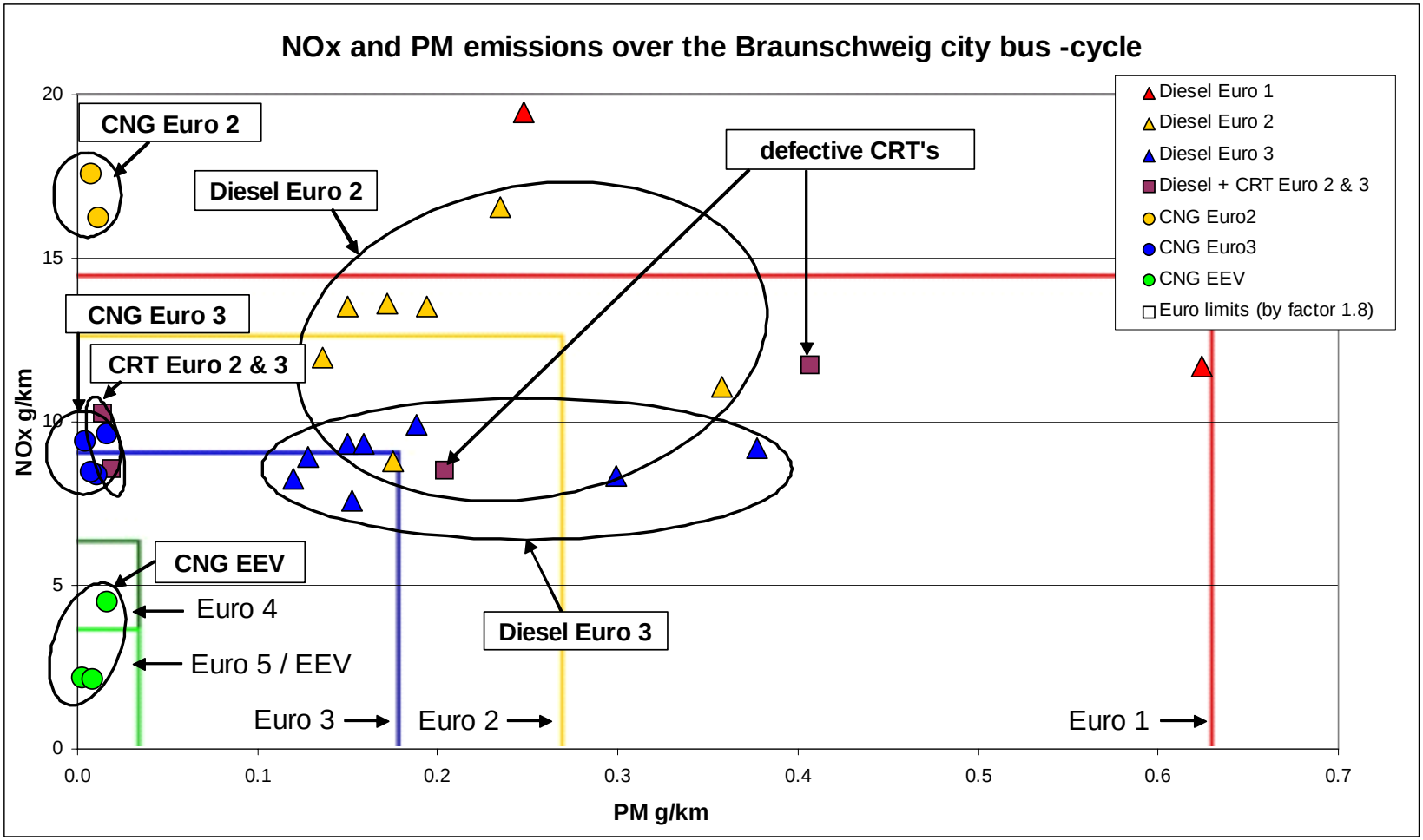

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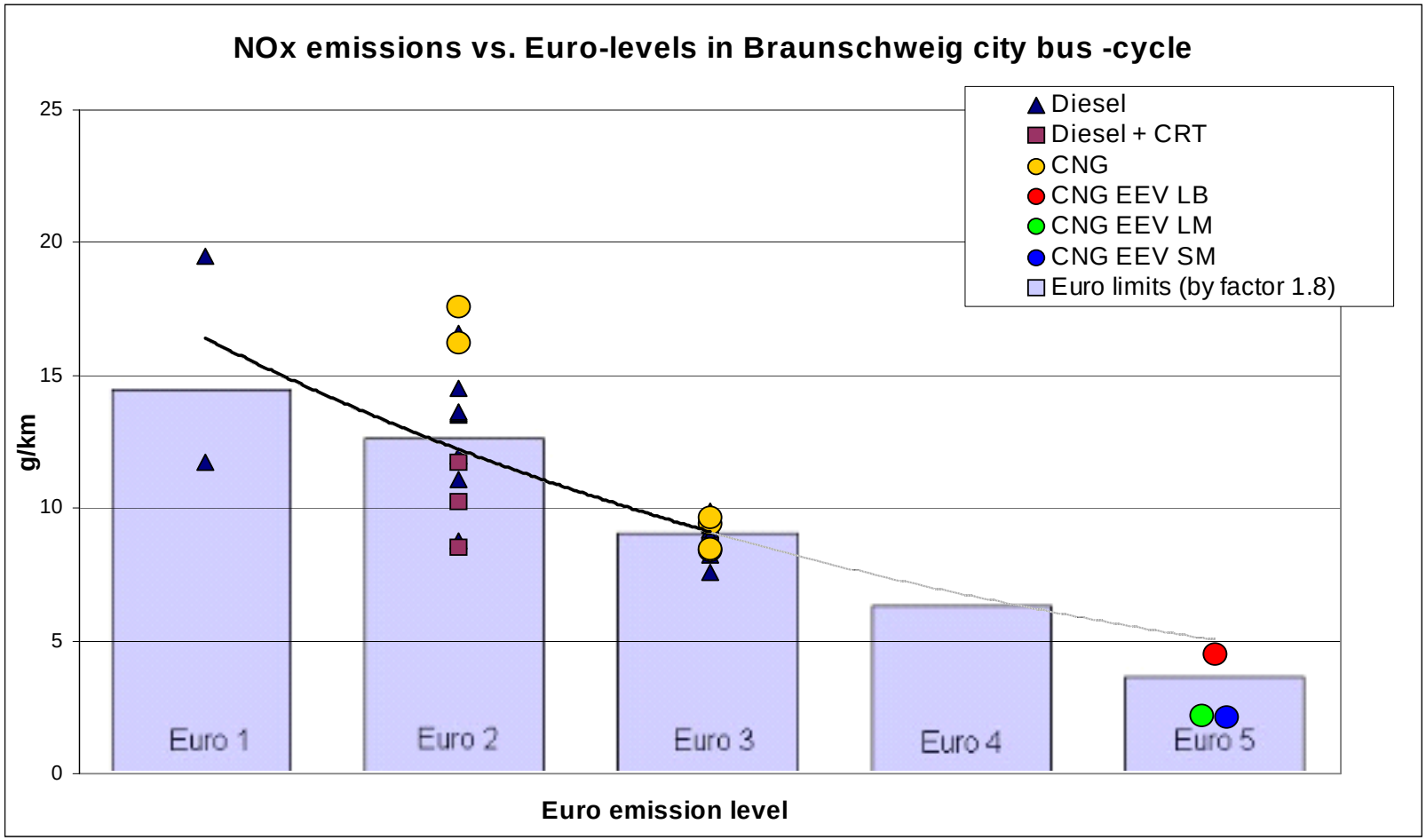

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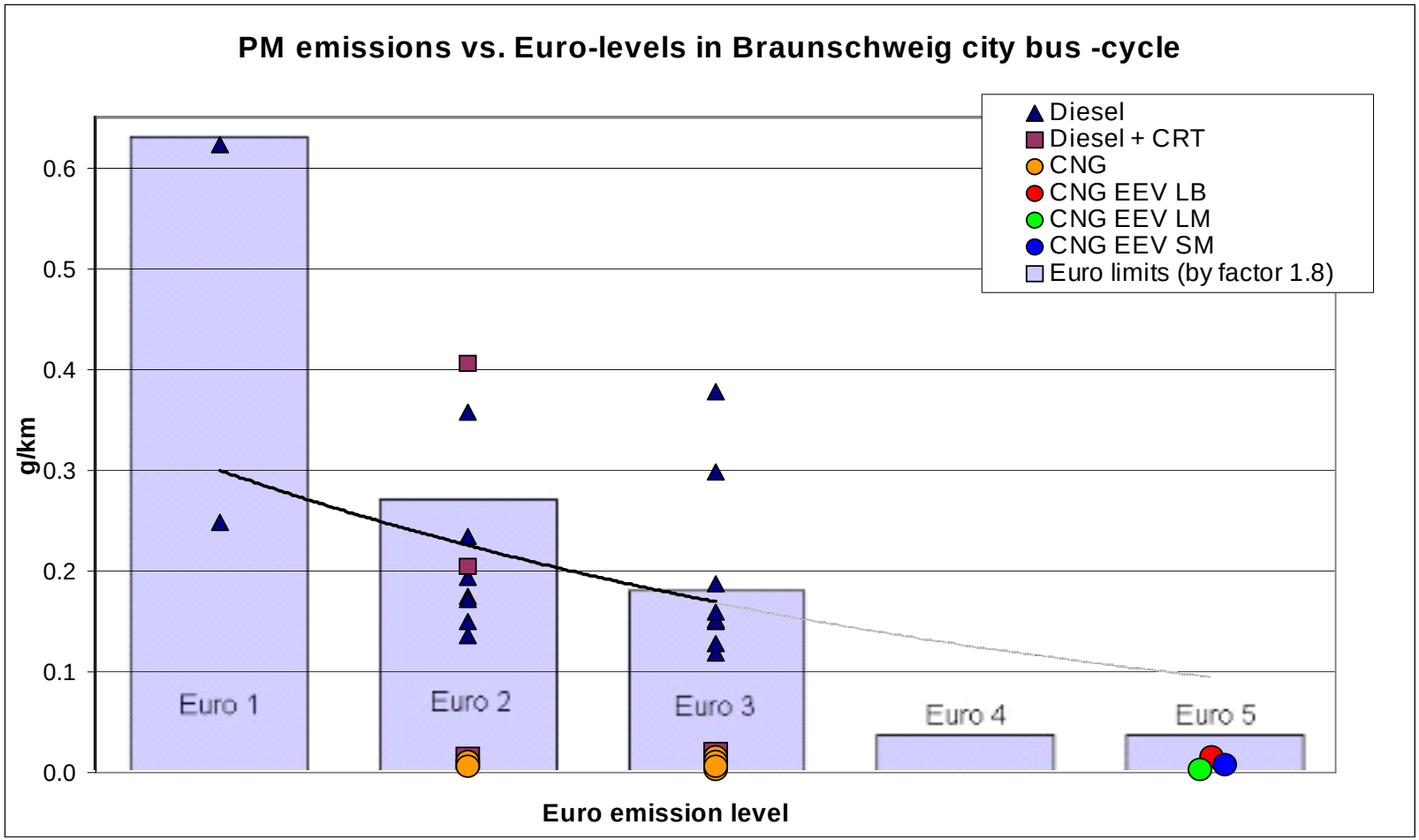

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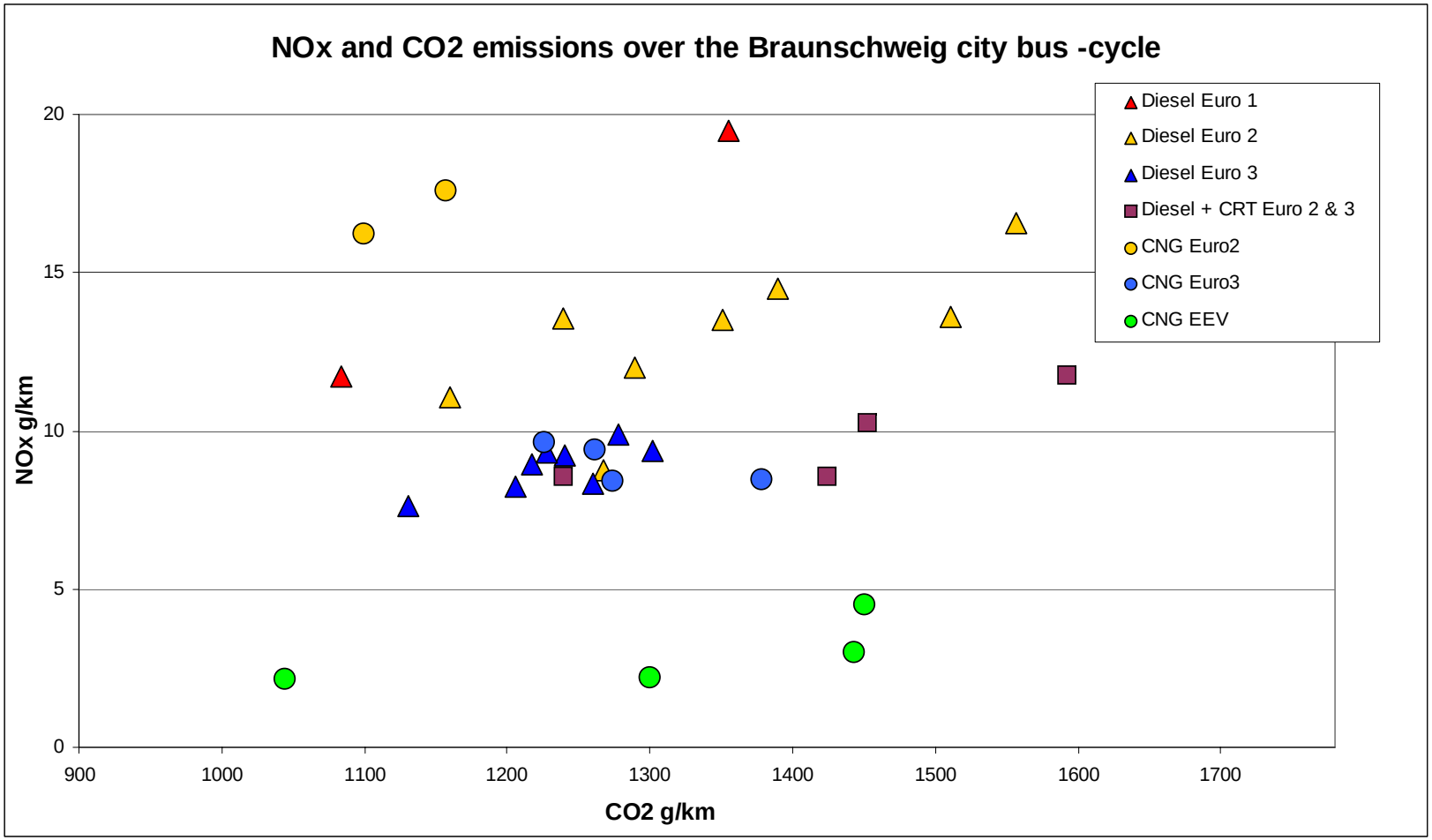

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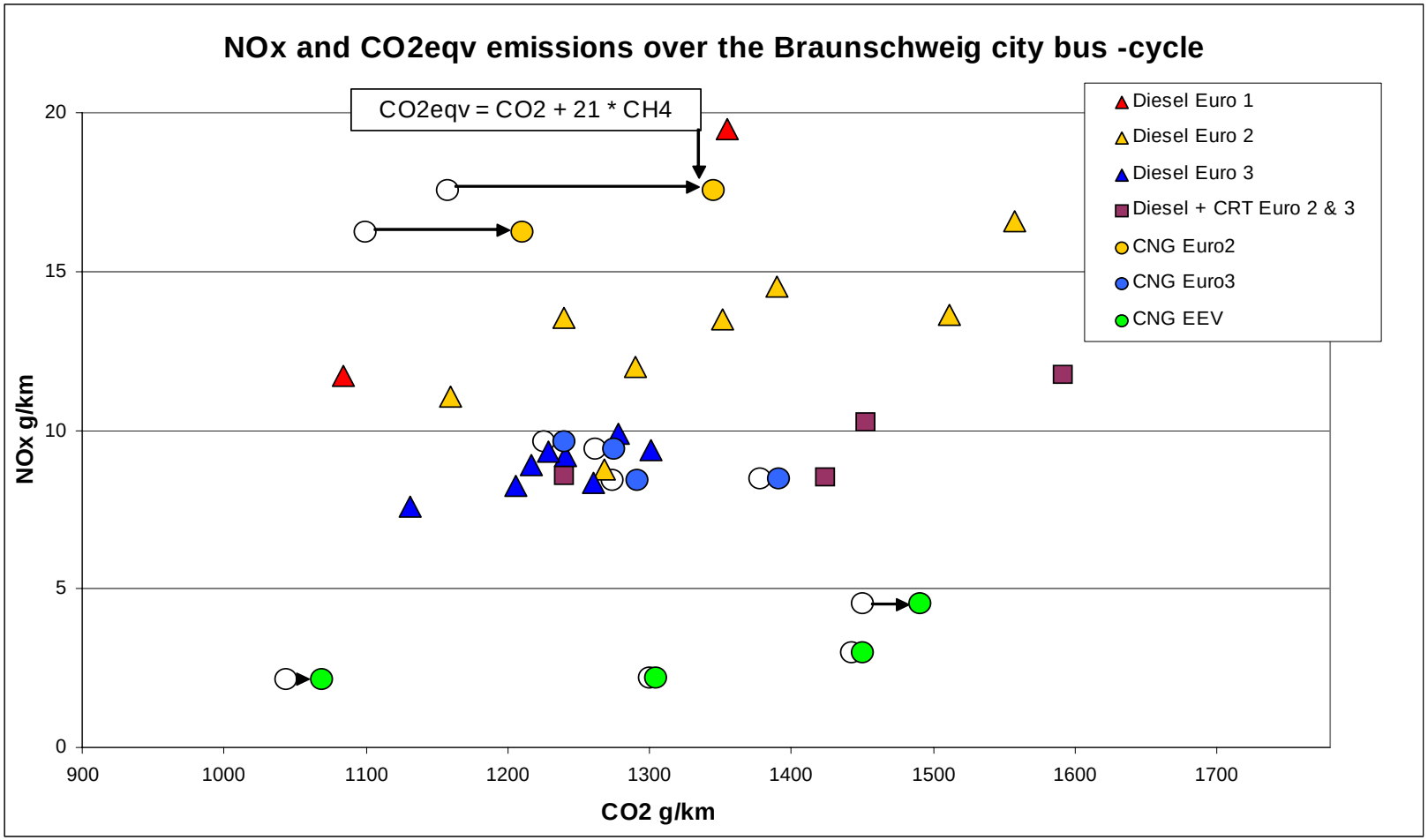
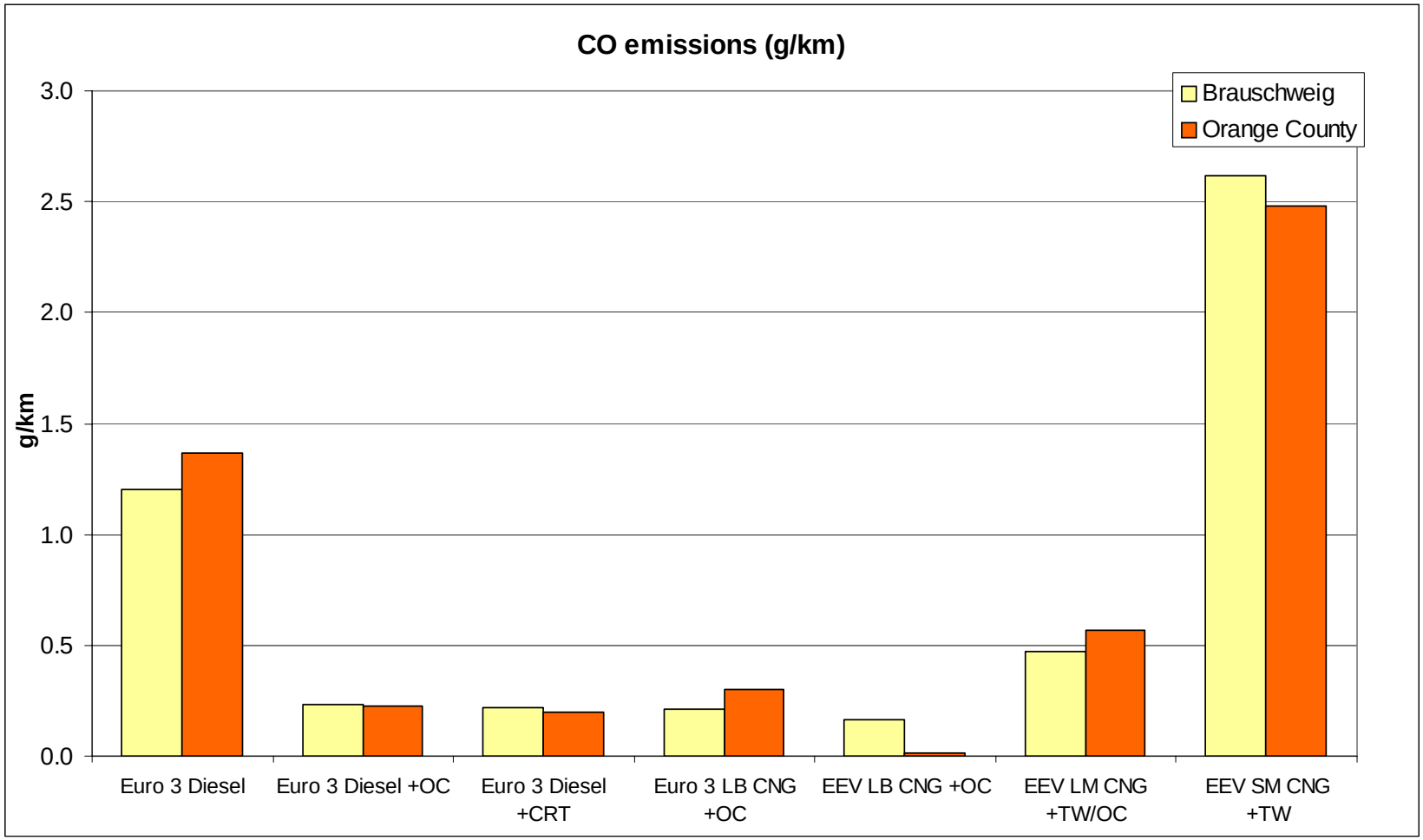
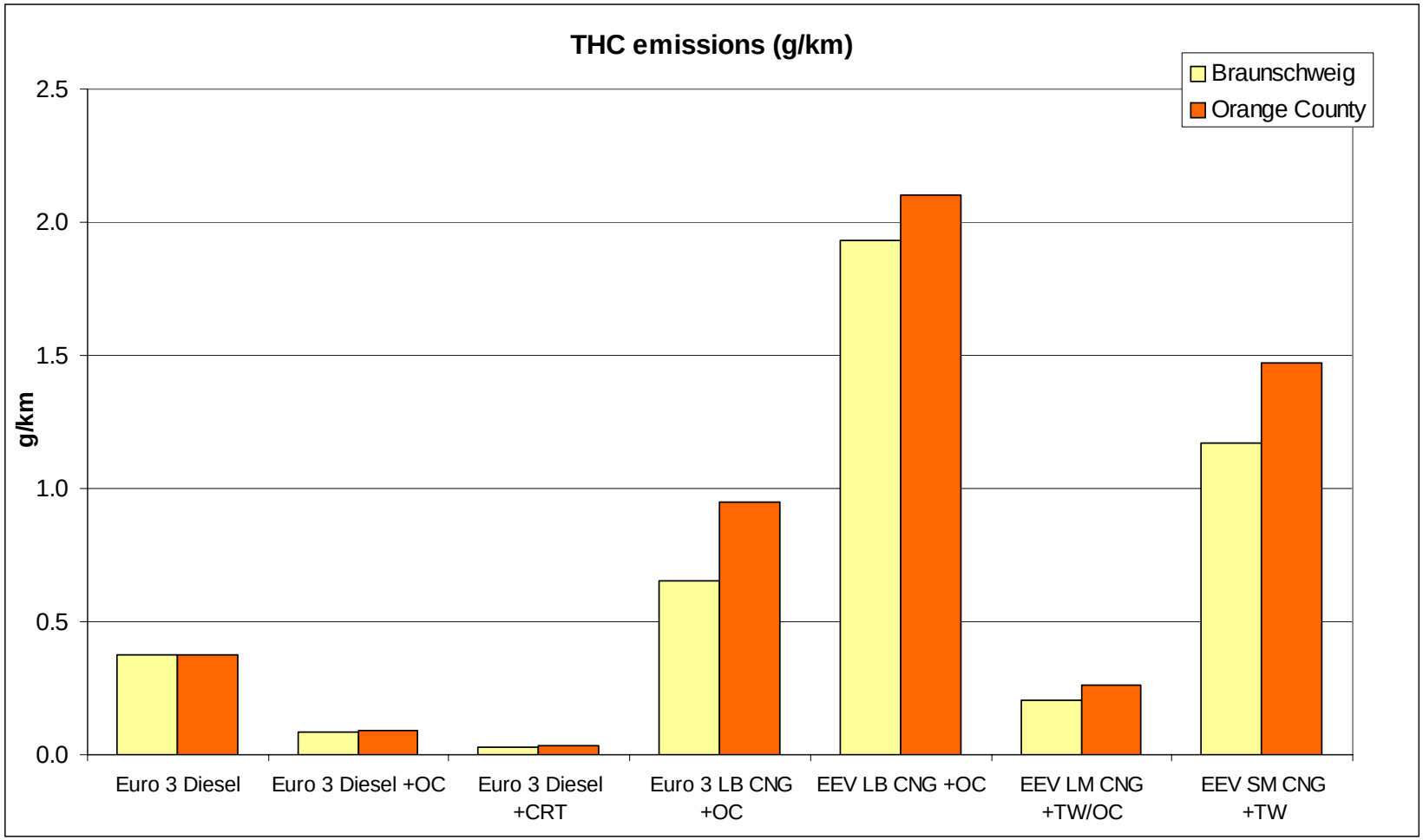


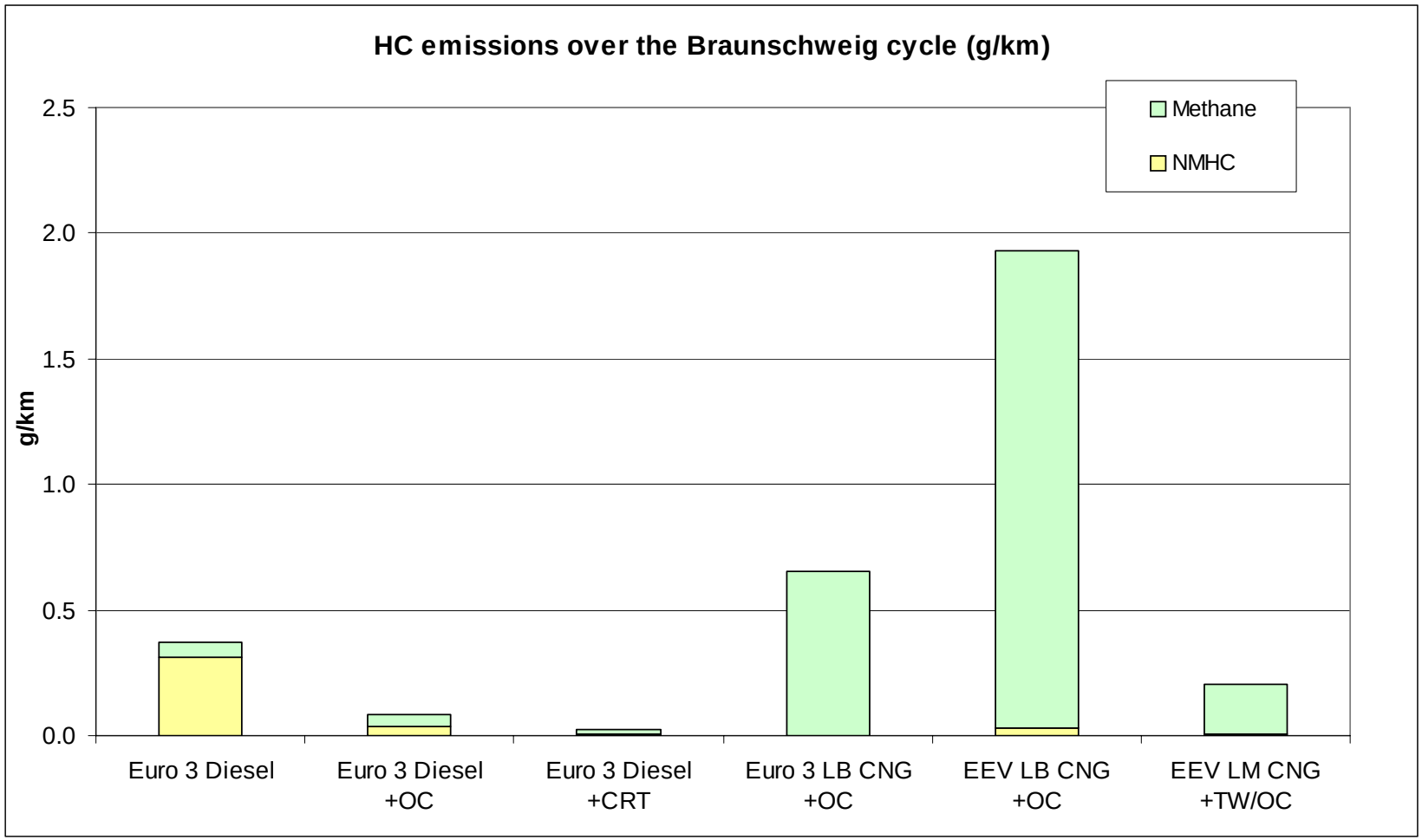
CO EMISSIONS/IANGV MATRIX



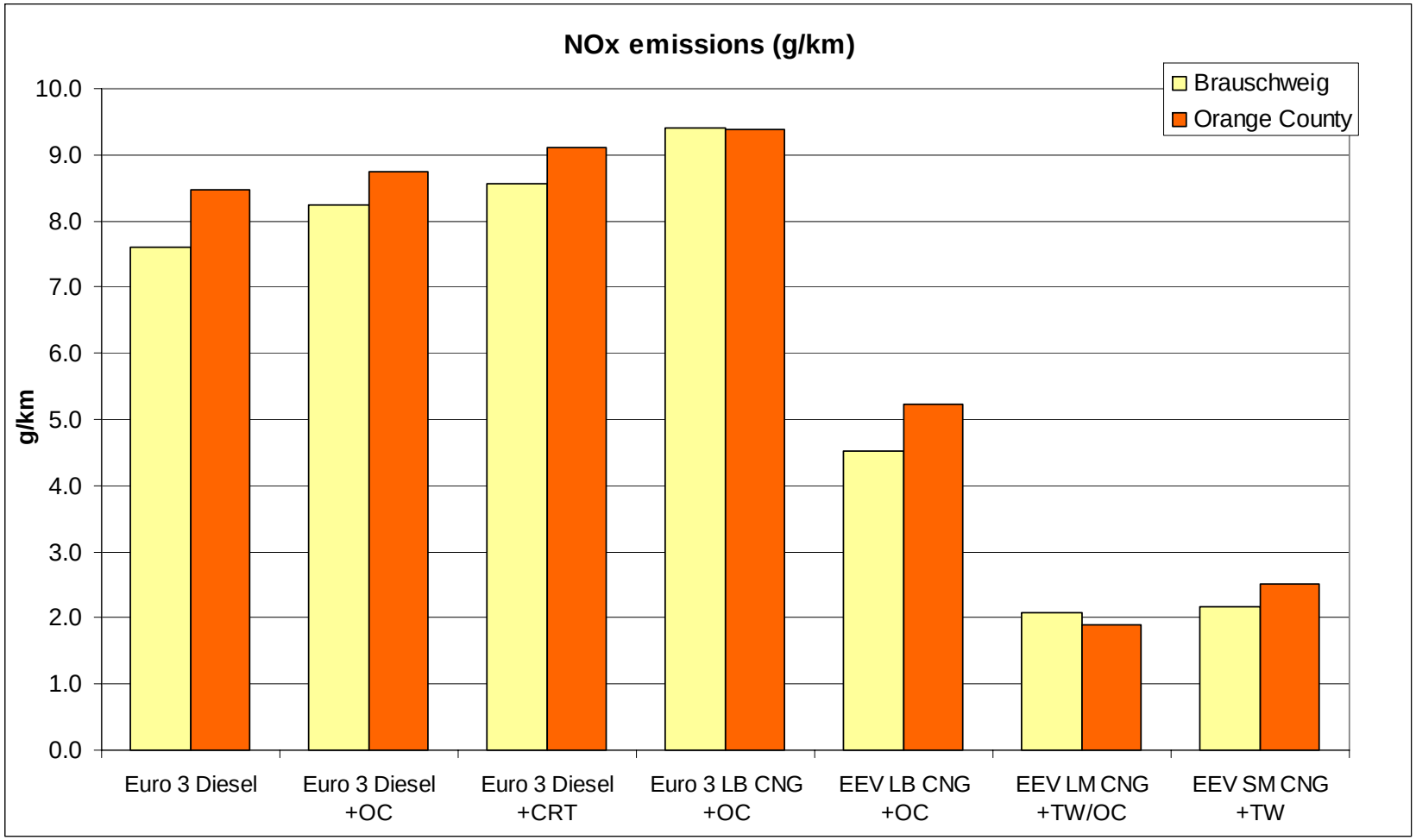
THC EMISSIONS/IANGV MATRIX



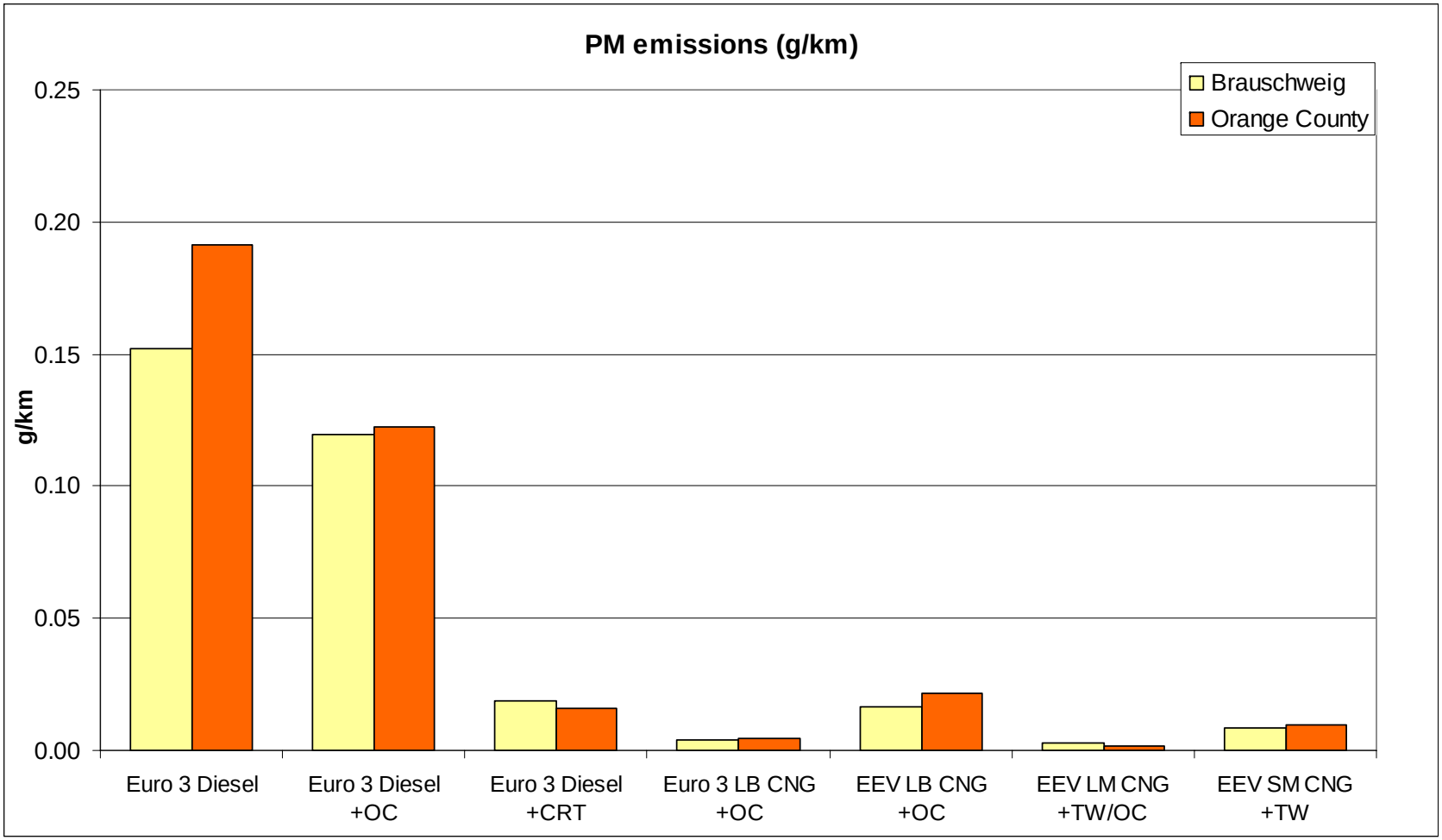
HC EMISSIONS/IANGV MATRIX



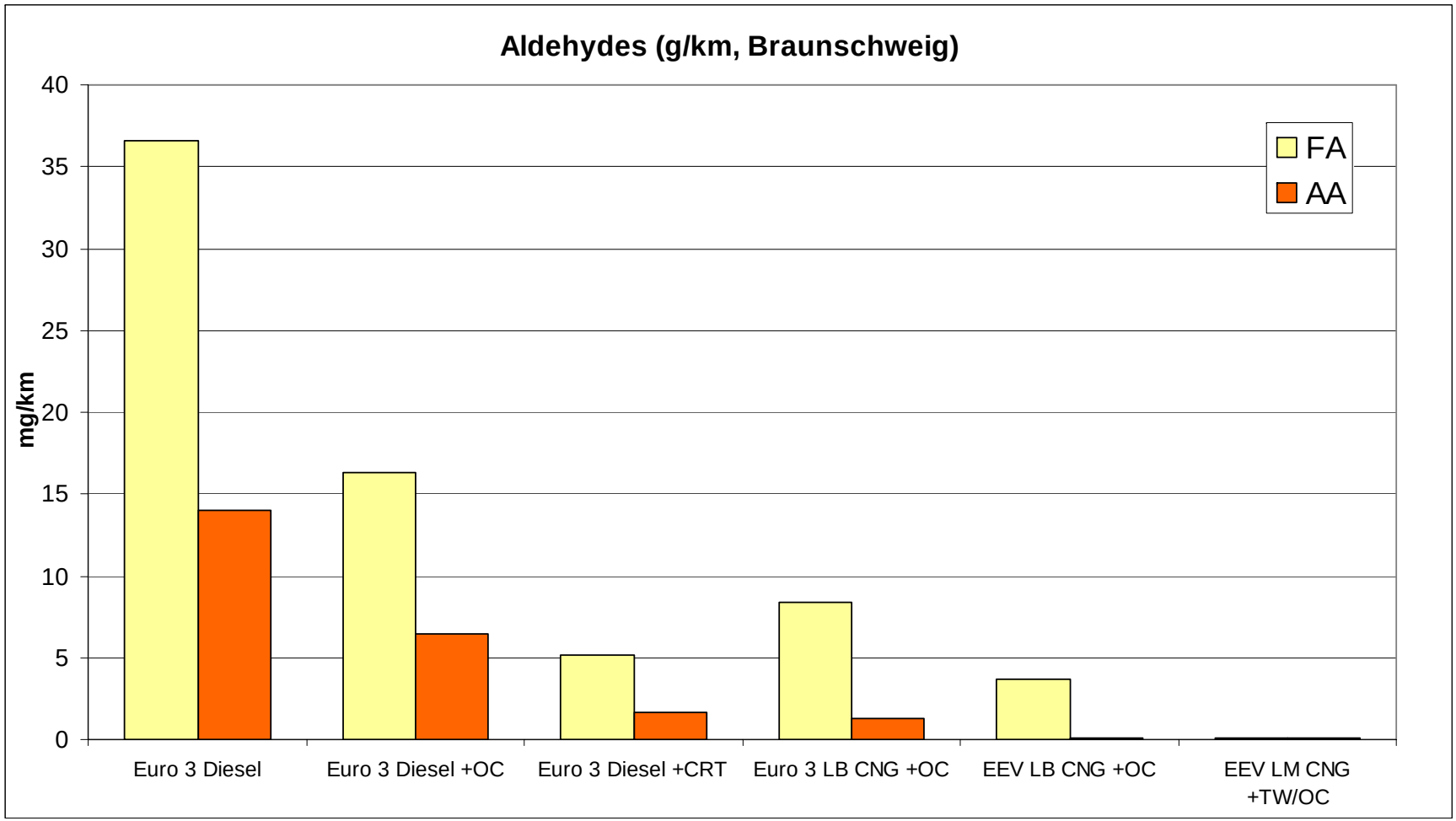
NOx EMISSIONS/IANGV MATRIX



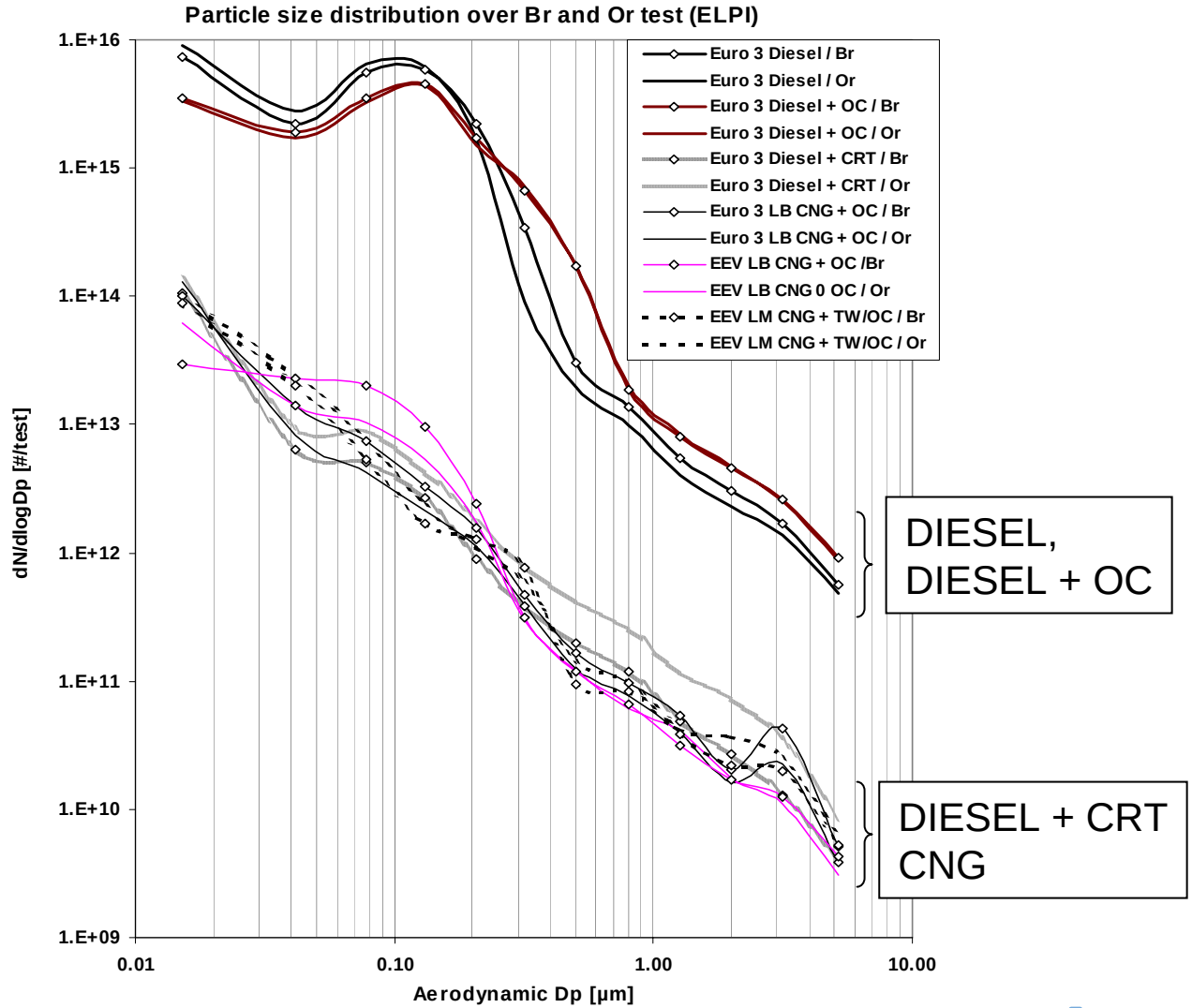
PM EMISSIONS/IANGV MATRIX



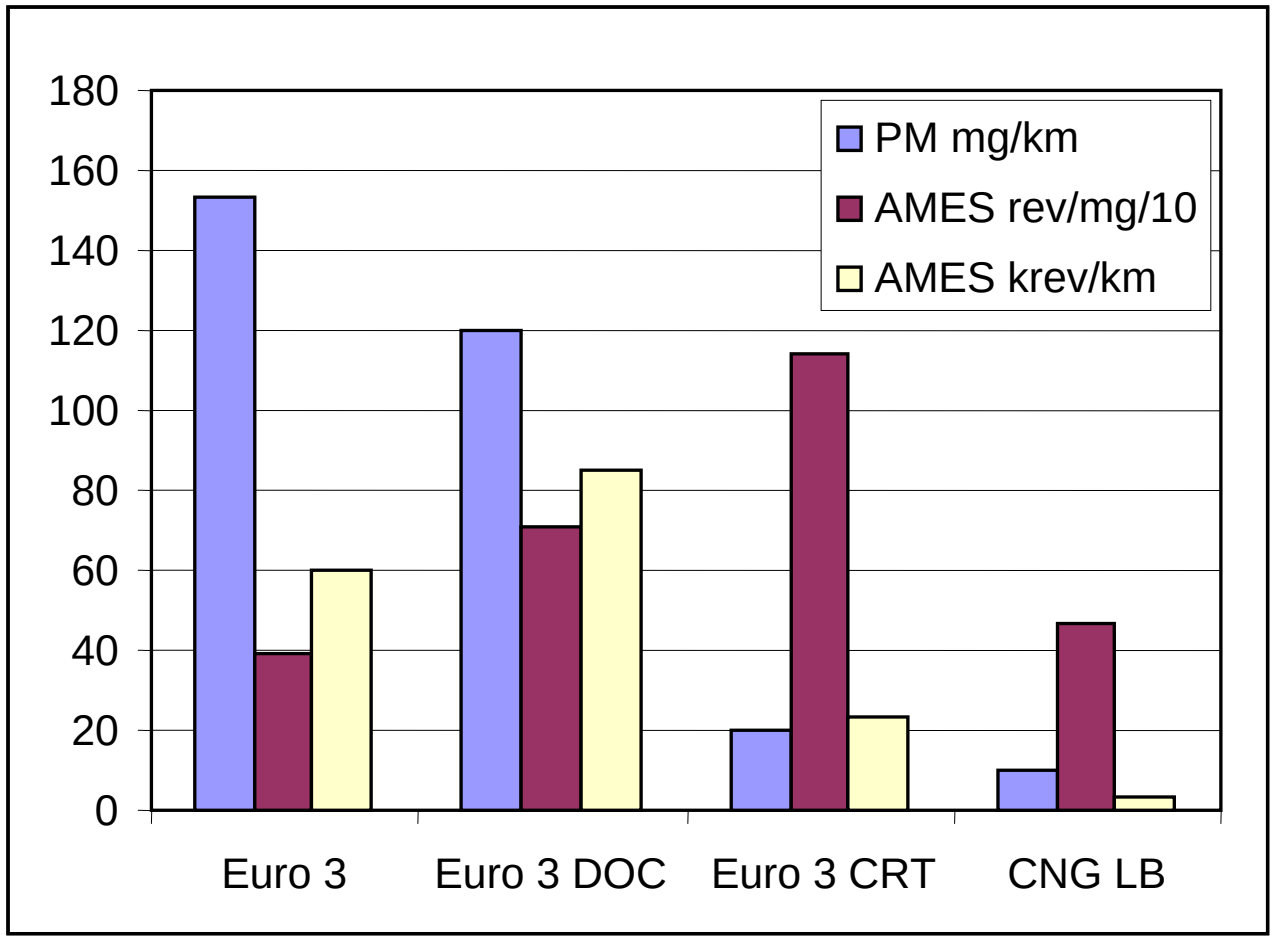
ALDEHYDE EMISSIONS/IANGV MATRIX



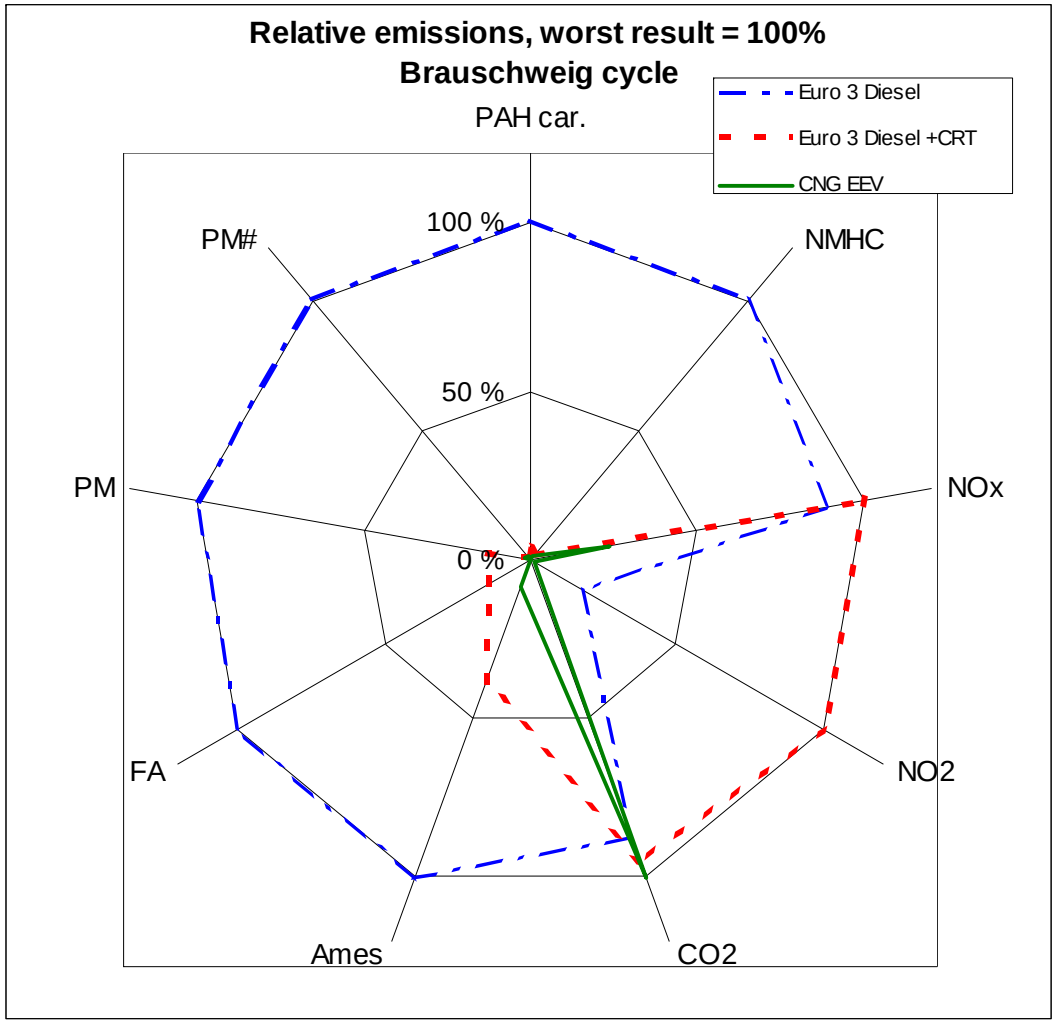
PARTICLE NUMBER SIZE DISTRIBUTION/IANGV MATRIX



AMES MUTAGENICITY/IANGV STUDY



COMPARISON DIESEL, DIESEL + CRT, CNG
IANGV STUDY



Items evaluated:

- Carcinogenic PAHs
- NMHC
- NO_x
- NO_2 (tailpipe)
- CO_2
- Ames mutagenicity
- Formaldehyde (FA)
- Particle mass (PM)
- Particle numbers (PM#)

CITY BUS EMISSION EVALUATION, CONCLUSIONS

- Both NO_X and PM emissions decrease along with newer Euro standards
  - "real life" emission trends point steadily downwards
  - exceptions can be found as certain bus models don't follow the general trend
- Results of older Euro 1 and Euro 2 buses spread significantly more than newer Euro 3 results
  - higher mileage and inaccurate fuel metering in transient situations
- Good and bad results for CRT buses
  - in some cases poor maintenance or failures caused CRT inactiveness
  - fully working devices give good results, even in the case of high mileage Euro 2 buses
- No significant difference in aggregate CO_2 emissions between diesel and natural gas buses
  - diesels consume less energy
  - CNG vehicles benefit from fuel chemistry

CITY BUS EMISSION EVALUATION, CONCLUSIONS

- PM emissions of natural gas buses are extremely low
  - independent of technology and mileage
- Stoichiometric NG combustion gives both lowest NO_x and CO_2 values
  - generally lean-burn combustion is claimed to be more fuel efficient
  - great differences in fuel consumption between different CNG buses
- Significant spread in THC emissions of CNG vehicles
  - moderate THC emissions for new CNG vehicles
  - high THC emissions for old CNG buses with ineffective catalysts
  - NMHC part low for all CNG vehicles
- Practically all CNG buses in Europe are catalyst equipped
  - excellent performance regarding unregulated emissions and exhaust toxicity
  - in this respect, the results of the IANGV study differ from many North American studies

ACKNOWLEDGEMENTS - SPONSORS

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  - International Association of Natural Gas Vehicles (IANGV)
  - Vehicles supplied by transport companies and manufacturers